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Abstract

Ignition hohlraum designs use low Z gas fill to slow down the inward progress of high Z ablated plasma from the hohlraum walls preventing large laser spot motion and capsule drive asymmetries. In order to optimize the ignition design, the gas hydro-coupling effect to a fusion capsule asymmetry is presently being assessed in experiments at the Omega laser facility with gas filled hohlraums and foam balls. Our experiments measure the effects of the pressure spike that is generated by direct gas heating by the drive laser beams on the capsule surrogate for various hohlraum gas fill densities (0-2.5 mg/cc). To isolate the effect of the gas-hydro coupling pressure, we have begun by using plastic "hohlraums" to reduce the x-ray ablation pressure.

The foam ball images measured by x-ray backlighting show increasing pole–hot pressure asymmetry for increasing gas pressure. In addition, the gas hydrodynamics is studied by imaging of a low concentration Xe gas fill dopant. The gas fill self-emission shows the early pressure spike and its propagation towards the foam ball, as well as the gas stagnation on the holraum axis at later times, both contributing to the capsule asymmetry. These first gas hydro-coupling results are compared to LASNEX simulations.

I INTRODUCTION

Present ignition hohlraum designs use low Z gas fill to slow down the inward progress of high Z ablated plasma from the hohlraum walls preventing large laser spot motion [1]. The spot motion causes capsule asymmetries, either through direct interaction or due to radiation non-uniformities that may compromise fuel ignition. On the other hand, the localized laser heating of the gas fill produces an early pressure spike on the target axis that may couple to the capsule. In order to optimize the ignition design, this gas hydro-coupling effect to a fusion capsule is presently being assessed in smaller scale experiments at the Omega laser facility with gas filled hohlraums and low density foam balls. The correct assessment of the gas hydro-coupling in simulations is vital for the ignition target design.

II EXPERIMENTAL SET-UP

The first gas hydro-coupling experiments were performed in scale 1.5 CH hohlraums, with an internal diameter of 2.4 mm, 3.6 mm length and a 75% laser entrance hole (LEH), as shown schematically in figure 1.

To isolate the effect of the gas-hydro coupling pressure, we have begun by using the plastic (CH) "hohlraums" to reduce the x-ray ablation pressure (Tr~70 eV) and to maximize the effect of hydrodynamic pressure on the capsule surrogate. A low density foam (SiO_2) ball (80 mg/cc) with a diameter of 0.6 mm was used as capsule surrogate for a good hydrodynamic coupling to the gas fill that results in a well resolved ball asymmetry.

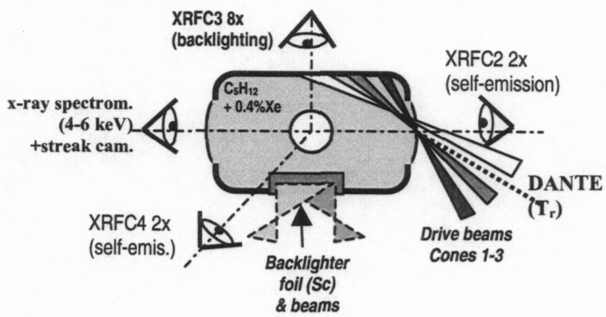

Figure 1 Experimental arrangement.

Our experiments measure the effects of gas hydrodynamics on the capsule surrogate symmetry for various hohlraum C_5H_{12} gas fill densities (0-2.5 mg/cc). The hohlraum is driven uniformly by 40 beams of the Omega laser displaced in three cones with 490 J/beam and 1 ns long square pulse. For a better drive uniformity all the beams have phase plates resulting in 0.8 mm focal spot size and a low laser backscattering (<1.5%).

The foam ball symmetry is measured side-on by large area x-ray backlighting [2] using a Sc foil, 6 backlighter beams with similar characteristics to the drive ones and an x-ray multi-framing camera (XRFC3) with 8x magnification as shown in figure 1. As a complementary diagnostics, the hohlraum gas dynamics is measured side-on and end-on by 2-dimensional spectral tracing of a Xe gas fill dopant with two x-ray framing cameras (XRFC1 and XRFC4). These cameras are filtered for the Xe L-shell emission for which the gas filled hohlraum including the wall is optically thin and that proved to be a very efficient radiator in other hohlraum drive experiments [3].

The Xe dopant concentration (0.4% partial pressure) is chosen low on one hand in order to have a neglectable influence on the gas dynamics according to the simulations, to be optically thin to its own radiation and on the other hand high enough so that the dopant emission flux allows 2-dimensional imaging. The Xe emission is sensitive to changes in the gas density and electron temperature [3], allowing us to study the gas dynamics and couple it to its influence on the foam ball symmetry given by the backlit pictures.

The dopant and backlighter x-ray emissions are probed with a spectrometer coupled to a x-ray streak camera and with a time integrated Henway spectrometer with a better spectral resolution. The soft x-ray flux and radiation temperature are measured through the LEH by a DANTE spectrometer [4].

III EXPERIMENTAL RESULTS

The foam ball symmentry and gas fill dynamics were measured for 5 different gas fill pressures, from vacuum to 2.35 mg/cc. Besides imaging the gas dynamics, the dopant self-emission pictures shows a bright background in the center that enables the imaging of the foam ball itself. Figure 2 shows typical foam ball imaging pictures obtained from self-emit and backlit, for vacuum, 0.55 and 0.93 mg/cc hohlraum gas fills.

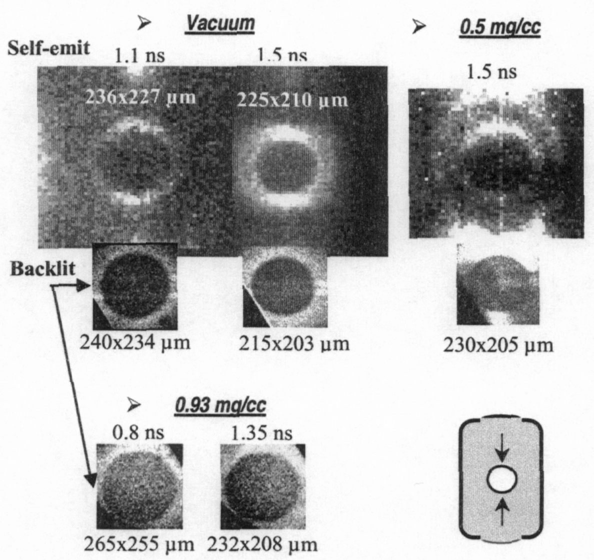

Figure 2 Foam ball images obtained from self-emit and backlit for vacuum, 0.55 mg/cc and 0.93 mg/cc hohlraum gas fills. The hohlraum orientation and the observed pole-hot asymmetry are also schematically shown.

The bright self-emission background has a spherical shape similar to the foam ball, occurs also in the vacuum case and its contrast decreases with the increasing gas fill pressure. For all these reasons we concluded that it is a bremsstrahlung emission of the ball ablation front that occurs even in the given conditions of low radiation drive. Moreover, the ball asymmetry obtained from the self-emission is quantitatively similar to that measured by backlighting with an error within the resolution element of the imaging method (figure 2). For higher gas fill pressures, the emission of the ball material overlaps with the gas dopant self-emission, making very difficult quantitative measurements of the ball self-emission.

From the large area backlighting measurements (Figure 1), in the vacuum case the foam ball compression is relatively symmetric, i.e. has low pole-hot asymmetry in the 5 µm range up to 1.4 ns, i.e. 0.4 ns after the drive beams are off. After that the pole-to-ecuator ball asymmetry increases. As it will be shown in the following by the self-emit pictures of the entire hohlraum volume, this late increased asymmetry is generated by the stagnation of the hohlraum wall material on the axis.

When gas fill is used, the foam ball is considerably more pancacked than in the vacuum case as predicted from simulations and this pole to equator asymmetry increases continuously in time. Moreover, the asymmetry at a certain time increases with the gas pressure (Fig. 1, 0.55 and 0.93 mg/cc).

The dopant self-emission pictures, shown in figure 3 provide an insight into the gas dynamics responsible for the foam ball asymmetries. The backligther (BL) emission, starting at 0.8 ns, occurs also on the self-emit pictures since the V filter used for the Xe L-shell emission has some transmission also in the region of He_α line of the Sc backlighter at 4.3 keV.

For the vacuum case during the drive pulse (0-1 ns) there is only a very low emission in the selected range given by the bremmsstrahlung of the laser spots on the hohlraum wall. Shortly after the drive is off, the foam ball can be seen due to its radiatively driven ablation front. At 1.2 ns CH wall material starts to stagnate on the axis in a region between the foam ball and the LEH and can be observed due to its bremmstrahlung emission. The increasingly stagnating wall material propagates on the axis and starts to interact with the foam ball at its poles at approximately 1.4 ns, as shown in figure 3, which explains the increased late pole-hot asymmetry shown in figure 2 for the vacuum case.

The self-emit pictures for the gas filled hohlraums revealed several interesting features of the gas dynamics (e.g. figure 3, 2.35 mg/cc case). At early times the heated gas front generated in the LEH region where the drive energy deposition is the highest moves from the LEH towards the foam ball, revealing the presence and motion of the predicted pressure spike. At later times, the gas heated by the laser cones, in particular cone 1, as well as the inwards motion of the hohlraum wall contribute to an increasing gas stagnation on the hohlraum axis.

Different from the vacuum case, these three processes result in an always present pole-hot asymmetry when gas fill is used, as predicted by the pre-experiment LASNEX simulations.

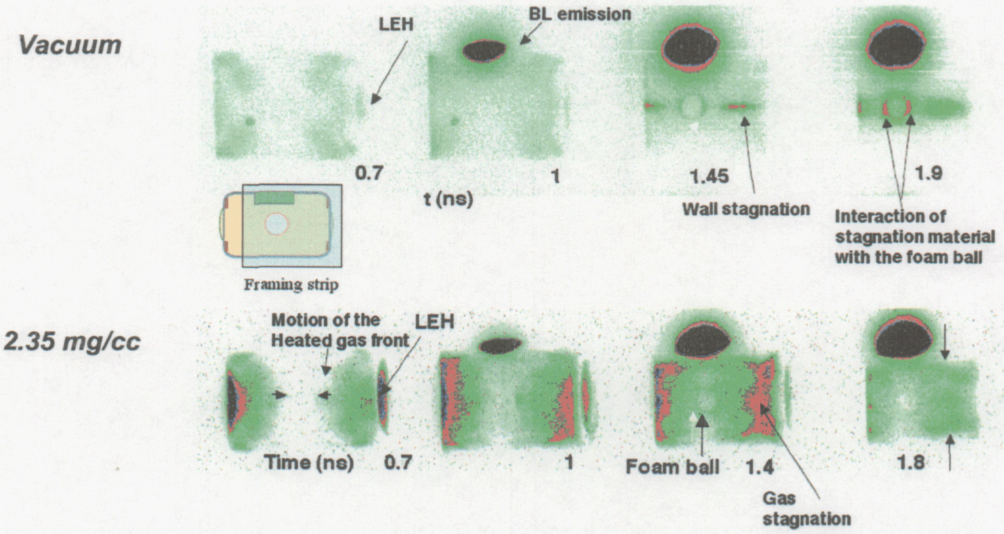

Figure 3 Typical dopant self-emission pictures for vacuum and 2.35 mg/cc gas fill; the orientation and size of the pictures relative to the hohlraum are also shown

Except for the higher gas fill pressures, i.e. 1.6 and 2.35 mg/cc, the overall self-emission intensity during the laser drive is very low and increases considerably after the drive is off when gas stagnation occurs on the axis. For this reason the motion of the heat front and consequently of the pressure spike from LEH towards the ball could be resolved only for the highest gas fill pressure (figure 3) from axial profiles of the self-emission, as shown in figure 4.

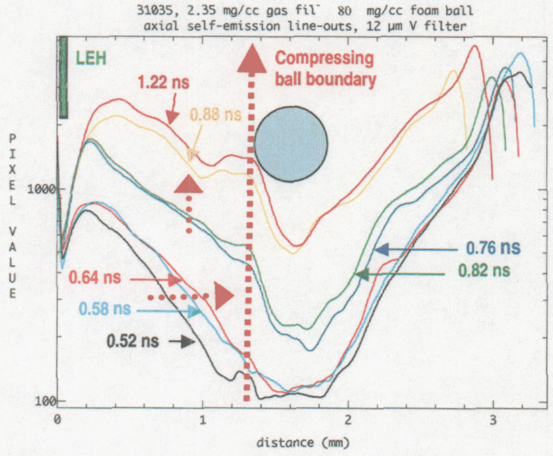

Figure 4 Axial self-emission profiles for 2.35 mg/cc gas fill (fig.3).

These profiles show at early times (0.5-0.7 ns) the heat front motion towards the ball. At intermediate times (0.76-0.86 ns) they show the heat front pile-up against the ball and at later times (0.9-1.22 ns) the gas stagnation on the axis, as well as a continuous compressing ball boundary.

For all used gas fill pressures the high density and temperature gas stagnation occurs on the axis shortly after the drive is off and lasts for several ns, as it was also confirmed by the soft x-ray power measurements performed with Dante.

Besides stagnation, the radius of the Xe gas dopant self-emission region decreases continuously in time as a result of the gas-wall interface inwards motion (figure 3, 2.35 mg/cc at 1.8 ns). As expected, the gas-wall interface motion slows down with the increasing gas fill pressure. This part of the hohlraum dynamics is quantitatively studied and compared to the simulations by radial profiles of the hohlraum taken at half distance between the LEH and the foam ball center, shown in figure 5.

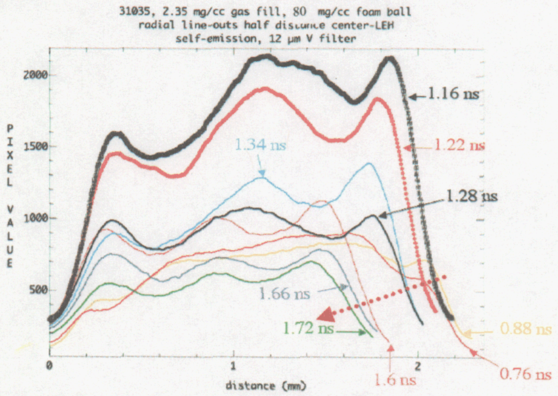

Figure 5 Radial self-emission profiles for 2.35 mg/cc gas fill showing the gas-wall interface motion

The profiles show a continuous gas-wall interface motion, as well as the occurrence of the gas stagnation, represented by a central peak on the profiles, starting at 1.1 ns.

IV COMPARISON TO SIMULATIONS AND DISCUSSION

The experimental results were compared with 2-dimensional LASNEX simulations using the realistic laser profiles and target designs. Figure 6 shows the distance traveled on pole and equator obtained from experiments and simulations for vacuum, 0.55 mg/cc and 0.93 mg/cc gas fills.

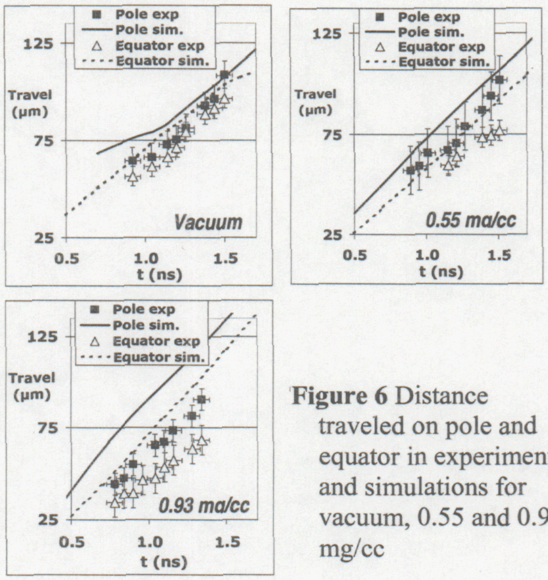

Figure 6 Distance traveled on pole and equator in experiment and simulations for vacuum, 0.55 and 0.93 mg/cc

The experiments and simulations are in good agreement regarding the pole-to-equator absolute asymmetry. However, the distance traveled during compression is higher in simulations than in experiments. Regarding the gas dynamics, the motion of the heat front from LEH towards the capsule surrogate (fig.4), having electron temperatures in the 1.2 keV range according to the simulations, is still to be compared with the simulations. Figure 7 shows the gas-wall interface motion inferred from the FWHM of the radial profiles obtained from experiments and post-processed from the simulations

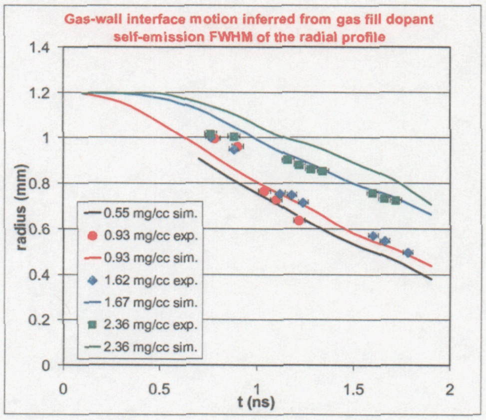

Figure 7 Gas-wall interface motion inferred from the half FWHM of the radial profiles (fig. 5) in experiments and simulations

As it can be noticed the gas-wall interface inwards motion is faster in experiments than in simulations and has a spatial offset. Moreover, the gas stagnation in the simulated self-emission occurs at about 1.9 ns which is considerably later than in experiments.

The differences between experiment and simulation are still under study. A possible explanation could be a faster heat conduction from the hohlraum wall to the gas in simulation than in experiments. This would lead to lower temperatures at the gas wall interface and consequently a slower interface motion as observed in figure 7 causing a delayed stagnation. In the same time this would also result in an earlier radiative heat transfer to the capsule surrogate, causing a faster compression in the simulations than in experiments.

After understanding the small differences between experimental results and simulations, the next set of experiments will deal with the study of gas hydro-coupling in the presence of x-ray ablation pressure at radiation temperatures in the 170 eV range. These experiments will be performed in Au lined CH hohlraums instead of massive Au in order to continue the study of gas dynamics from dopant self-emission by 2-dimensional imaging through the hohlraum wall.

These studies are very important in the choice of the gas fill and its density in the ignition hohlraum design [1].

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